Low-pressure mercury vapor discharge lamp

The invention relates to a low-pressure mercury vapor discharge lamp comprising an at least partly substantially cylindrical discharge vessel with a length L_{dv} and with an internal diameter D_{in},

the discharge vessel enclosing, in a gastight manner, a discharge space provided with a mixture of inert gases and with mercury,

the discharge vessel comprising discharge means for maintaining a discharge in the discharge space.

The invention also relates to a compact fluorescent lamp.

In mercury vapor discharge lamps, mercury constitutes the primary component for the (efficient) generation of ultraviolet (UV) light. A luminescent layer comprising a luminescent material may be present on an inner wall of the discharge vessel to convert UV to other wavelengths, for example to UV-B and UV-A for tanning purposes (sun panel lamps) or to visible radiation for general illumination purposes. Such discharge lamps are therefore also referred to as fluorescent lamps. Alternatively, the ultraviolet light generated may be used for manufacturing germicidal lamps (UV-C). The discharge vessel of a low-pressure mercury vapor discharge lamp is usually circular and comprises both elongate and compact embodiments. Generally, the tubular discharge vessel of a compact fluorescent lamp comprises a collection of relatively short straight parts having a relatively small diameter, which straight parts are connected together by means of bridge parts or via bent parts. A compact fluorescent lamp is usually provided with an (integrated) lamp cap. Normally, the means for maintaining a discharge in the discharge space are electrodes arranged in the discharge space. In an alternative embodiment, the low-pressure mercury vapor discharge lamp comprises a so-called electrodeless low-pressure mercury vapor discharge lamp.

In the description and claims of the current invention, the designation "nominal operation" is used to refer to operating conditions where the mercury-vapor pressure is such that the radiation output of the lamp is at least 80% of that when the light output is maximal, i.e. under operating conditions where the mercury-vapor pressure is optimal. In addition, in the description and claims, the "initial radiation output" is defined as the radiation output of the discharge lamp 1 second after switching-on of the discharge lamp,

and the "run-up time" is defined as the time needed by the discharge lamp to reach a radiation output of 80% of that during optimum operation.

Low-pressure mercury-vapor discharge lamps are known comprising an amalgam. Such discharge lamps have a comparatively low mercury-vapor pressure at room temperature. As a result, amalgam-containing discharge lamps have the disadvantage that the initial radiation output is also comparatively low when a customary power supply is used to operate said lamp. In addition, the run-up time is comparatively long because the mercury-vapor pressure increases only slowly after switching-on of the lamp. Apart from amalgam-containing discharge lamps, low-pressure mercury-vapor discharge lamps are known which comprise both a (main) amalgam and a so-called auxiliary amalgam. If the auxiliary amalgam comprises sufficient mercury, the lamp will have a relatively short run-up time. Immediately after the lamp has been switched on, i.e. during preheating of the electrodes, the auxiliary amalgam is heated by the electrode so that it relatively rapidly dispenses a substantial portion of the mercury that it contains. In this respect, it is desirable that, prior to being switched on, the lamp has been idle for a sufficiently long time to allow the auxiliary amalgam to take up sufficient mercury. If the lamp has been idle for a comparatively short period of time, the reduction of the run-up time is only small. In addition, in that case the initial radiation output is (even) lower than that of a lamp comprising only a main amalgam, which can be attributed to the fact that a comparatively low mercury-vapor pressure is adjusted in the discharge space by the auxiliary amalgam. An additional problem encountered with comparatively long lamps is that it takes comparatively much time for the mercury liberated by the auxiliary amalgam to spread throughout the discharge vessel, so that after switching-on of such lamps, they show a comparatively bright zone near the auxiliary amalgam and a comparatively dark zone at a greater distance from the auxiliary amalgam, which zones disappear after a few minutes.

In addition, low-pressure mercury-vapor discharge lamps are known which are not provided with an amalgam and contain only free mercury. These lamps, also referred to as mercury discharge lamps, have the advantage that the mercury-vapor pressure at room temperature and hence the initial radiation output are relatively high compared with amalgam-containing discharge lamps and compared with discharge lamps comprising a (main) amalgam and an auxiliary amalgam. In addition, the run-up time is comparatively short. After having been switched on, comparatively long lamps of this type also show a substantially constant brightness over substantially the whole length, which can be attributed to the fact that the vapor pressure (at room temperature) is sufficiently high at the time of switching-on of these lamps.

A relatively large amount of mercury is necessary for the low-pressure mercury vapor discharge lamps known in the art in order to realize a sufficiently long lifetime. A drawback of the known discharge lamps is that they form a burden on the environment. This is in particular the case if the discharge lamps are injudiciously processed after the end of the lifetime.

It is an object of the invention to eliminate the above disadvantage wholly or partly. In particular, it is an object of the invention to provide a low-pressure mercury vapor discharge lamp for which the burden on the environment is reduced. According to a first measure of the invention, a low-pressure mercury vapor discharge lamp of the kind mentioned in the opening paragraph is for this purpose characterized in that the ratio of the weight of mercury m_{Hg} in the discharge vessel and the product of the internal diameter D_{in} and the length of the discharge vessel L_{dv} is given by the relation:

$$\frac{m_{Hg}}{D_{in} \times L_{dv}} = C,$$

wherein $C \leq 0.01$ $\mu g/mm^2$.

A discharge vessel of a low-pressure mercury vapor discharge lamp according the first measure of the invention having a ratio of the weight (expressed in μg) of mercury and the product of the internal diameter (expressed in mm) and the length (expressed in mm) of the discharge vessel which is below 0.01 $\mu g/mm^2$, contains a relatively small amount of mercury. The mercury content is considerably lower than what is normally provided in known low-pressure mercury vapor discharge lamps. The value $C \leq 0.01$ $\mu g/mm^2$ causes the low-pressure mercury vapor discharge lamp according to the first measure of the invention to operate as a so-called "unsaturated" mercury vapor discharge lamp at certain ambient temperatures.

The above relation shows that the amount of mercury in the discharge lamp is proportional to the product of the internal diameter D_{in} and the length of the discharge vessel L_{dv} . Roughly speaking, the amount of mercury in the discharge lamp is proportional to the size of the internal surface of the discharge vessel. Experiments have shown that the formula can be applied at least to low-pressure mercury vapor discharge lamps with a diameter of the discharge vessel in a range from approximately 3.2 mm (1/8 inch) to approximately 38 mm

(12/8 inch) and to (corresponding) lengths in a range from approximately 10 mm (1/3 foot) and approximately $27 \cdot 10^2$ mm (9 feet) of the discharge vessels.

In the description and claims of the current invention, the designations "unsaturated" or "unsaturated mercury conditions" are used to refer to a low-pressure mercury vapor discharge lamp in which the amount of mercury dosed into the discharge vessel (during manufacture) of the low-pressure mercury vapor discharge lamp is equal to or lower than the amount of mercury needed for a saturated mercury vapor pressure during nominal operation of the discharge lamp.

Operating a mercury vapor discharge lamp under unsaturated mercury conditions has a number of advantages. Generally speaking, the performance of unsaturated mercury discharge lamps (light output, efficacy, power consumption, etc.) is independent of the ambient temperature as long as the mercury pressure is unsaturated. This results in a constant light output which is independent of the way of burning the discharge lamp (base up versus base down, horizontally versus vertically). In practice, a higher light output of the unsaturated mercury vapor discharge lamp is obtained in the application. Unsaturated lamps combine a higher light output and an improved efficacy in applications at elevated temperatures with minimum mercury content. This results in ease of installation and in freedom of design for lighting and luminaire designers. An unsaturated mercury discharge lamp gives a relatively high system efficacy in combination with a relatively low Hg content. In addition, unsaturated lamps have an improved lumen maintenance. Since the trends towards further miniaturization and towards more light output from one luminaire will continue the forthcoming years, it may be anticipated that problems with temperature in application will occur more frequently in the future. With an unsaturated mercury vapor discharge lamp these problems are considerably reduced. Unsaturated lamps combine a minimum mercury content with an improved lumen per Watt performance at elevated temperatures.

When the performance of unsaturated lamps is compared with that of so-called cold-spot or to so-called amalgam low-pressure mercury vapor discharge lamps, the following advantages can be mentioned. In a "cold-spot" mercury discharge lamp, the mercury pressure is controlled by a so-called cold-spot temperature somewhere in the discharge vessel. In an amalgam mercury discharge lamp, the mercury pressure is controlled by means of an amalgam; in a number of such amalgam discharge lamps additionally an auxiliary amalgam is employed. The initial radiation output and the run-up time and ignition voltage of an unsaturated mercury discharge lamp are comparable to those of cold-spot

lamps. Other properties like size (no cold-spot area necessary in an unsaturated discharge lamp; e.g. by introducing long stems), lifetime, color temperature, color rendering index and reliability are at the same level as in known mercury discharge lamps. The lumen maintenance of unsaturated lamps is expected to be better than that of the known compact fluorescent lamps (CFL) and fluorescent discharge lamps (TL). With unsaturated lamps miniaturization can be driven to its limits because thermal problems are minimized. For new installation unsaturated mercury discharge lamps this can result in a reduction of the total costs of ownership.

The first measure according to the invention enables the manufacturing of long-life low-pressure mercury vapor discharge lamps which operate under conditions of unsaturated mercury content. Such unsaturated mercury discharge lamps have the advantage that the burden on the environment is reduced.

Preferably, the value of C is in a range of $0.0005 \leq C \leq 0.005$ $\mu g/mm^2$. In this regime of C, the upper limit of the mercury content in the discharge lamp is further reduced. The low-pressure mercury vapor discharge lamp according to the invention operates as an unsaturated mercury vapor discharge lamp in this preferred embodiment of the invention.

Instead of expressing the mercury content in the discharge vessel in terms of the amount of mercury present in the discharge vessel, the mercury content may also be expressed as the pressure of mercury in the discharge vessel of the low-pressure mercury vapor discharge lamp. According to a second measure of the invention, a low-pressure mercury vapor discharge lamp of the kind mentioned in the opening paragraph is for this purpose characterized in that the product of the mercury pressure p_{Hg} and the internal diameter D_{in} of the discharge vessel is in a range of $0.13 \leq p_{Hg} \times D_{in} \leq 8$ Pa.cm.

A discharge vessel of a low-pressure mercury vapor discharge lamp according to the second measure of the invention, in which the product of the mercury pressure (expressed in Pa) and the internal diameter (expressed in mm) of the discharge vessel which is in said range from, contains a relatively small amount of mercury. The mercury content is considerably lower than what is normally provided in known low-pressure mercury vapor discharge lamps. The low-pressure mercury vapor discharge lamp according to the second measure of the invention operates as a so-called "unsaturated" mercury vapor discharge lamp.

Preferably, the product of the mercury pressure p_{Hg} and the internal diameter D_{in} of the discharge vessel is in a range of $0.13 \leq p_{Hg} \times D_{in} \leq 4$ Pa.cm. In this preferred regime of $p_{Hg} \times D_{in}$, the mercury content in the discharge lamp is further reduced. The low-

pressure mercury vapor discharge lamp according to the invention operates as an unsaturated mercury vapor discharge lamp in this preferred embodiment of the invention.

A preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention is characterized in that the discharge vessel contains less than approximately 0.1 mg mercury. There is a tendency in governmental regulations to prescribe a maximum amount of mercury present in a low-pressure mercury vapor discharge lamp such that, if the discharge lamp comprises less than said prescribed amount, the user is allowed to dispose of the lamp without environmental restrictions. If a mercury discharge lamp contains less than 0.2 mg of mercury, such requirements are largely fulfilled. Preferably, the discharge vessel contains approximately 0.05 mg mercury ($C \approx 0.0013$) or less.

It is not an easy task to operate a low-pressure mercury vapor discharge lamp under unsaturated mercury conditions according to the first and/or second measure of the invention while simultaneously realizing a relatively long life of the discharge lamp. It is known that measures are taken in low-pressure mercury vapor discharge lamps to reduce the amount of mercury that is no longer able to contribute to the reactive atmosphere in the discharge space in the discharge vessel during life of the discharge lamp. Mercury is lost owing to the interaction of mercury and materials present in the lamp (such as glass, coatings, electrodes), and parts of the inner wall of the discharge vessel are blackened. Wall blackening does not only give rise to a lower light output, but also gives the lamp an unaesthetic appearance, particularly because the blackening occurs irregularly, for example in the form of dark stains or dots.

A preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention is characterized in that the discharge means comprises electrodes arranged in the discharge space, in that an electrode shield at least substantially surrounds at least one of the electrodes, and in that the electrode shield is made from a ceramic material or from stainless steel.

Electrodes in low-pressure mercury-vapor discharge lamps include a so-called emitter material having a low so-called work function for supplying electrons to the discharge (cathode function) and receiving electrons from the discharge (anode function). Known materials having a low work function are, for example, barium (Ba), strontium (Sr), and calcium (Ca). It has been observed that, during operation of low-pressure mercury-vapor discharge lamps, material (barium and strontium) of the electrode(s) is subject to volatilization. It has been found that, in general, the emitter material is deposited on the inner surface of the discharge vessel. It has further been found that the above-mentioned Ba (and

Sr), when deposited elsewhere in the discharge vessel, no longer participates in the light-generating process. The deposited (emitter) material further forms mercury-containing amalgams on the inner surface, as a result of which the quantity of mercury available for the discharge operation gradually decreases, which may adversely affect the service life of the lamp. In order to compensate for such a loss of mercury, the provision of an electrode shield surrounding the electrode(s) and made from a ceramic material reduces the reactivity of materials surrounded by the electrode shield relative to the mercury present in the discharge vessel, leading to the formation of amalgams (Hg-Ba, Hg-Sr). In addition, the use of an electrically insulating material precludes the development of short circuits in the electrode wires and/or in a number of turns of the electrode(s).

The electrode shield itself should not appreciably absorb mercury. To achieve this, the material of the electrode shield comprises at least an oxide of at least one element of the series formed by magnesium, aluminum, titanium, zirconium, yttrium, and the rare earths. Preferably, the electrode shield is made from a ceramic material which comprises aluminum oxide. Particularly suitable electrode shields are manufactured from so-called densely sintered Al_2O_3, also referred to as PCA. An additional advantage of the use of aluminum oxide is that an electrode shield made of such a material is resistant to relatively high temperatures (>250°C). At such relatively high temperatures, there is an increased risk that the (mechanical) strength of the electrode shield decreases, thus adversely affecting the shape of the electrode shield. (Emitter) material originating from the electrode(s) and deposited on an electrode shield of aluminum oxide which is at a much higher temperature cannot or hardly react with the mercury present in the discharge, as result of said high temperature, so that the formation of mercury-containing amalgams is at least substantially precluded. In this manner, the use of an electrode shield in accordance with the invention serves a dual purpose. On the one hand, it is effectively precluded that the material originating from the electrode(s) is deposited on the inner surface of the discharge lamp, and, on the other hand, it is precluded that (emitter) material deposited on the electrode shield forms amalgams with the mercury present in the discharge lamp. Preferably, in operation, the temperature of the electrode shield exceeds 250°C. An advantage of such a relatively high temperature is that, in particular, in the initial stage, the electrode shield becomes hotter than in the known lamp, as a result of which any mercury bound to the electrode shield is released more rapidly and more readily. In an alternative embodiment, the electrode shield is made from stainless steel. An electrode shield made of stainless steel is dimensionally stable, is corrosion resistant, and exhibits a relatively low heat emissivity at relatively high temperatures (above 400°C).

An alternative embodiment of the discharge lamp in accordance with the invention comprises the so-called electrodeless discharge lamps, in which the means for maintaining an electric discharge are situated outside a discharge space surrounded by the discharge vessel. Generally said means are formed by a coil provided with a winding of an electrical conductor, with a high-frequency voltage, for example having a frequency of approximately 3 MHz, being supplied to said coil in operation. In general, said coil surrounds a core of a soft-magnetic material.

An alternative, preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention is characterized in that the product of the pressure of the inert gas mixture p_{igm} and the internal diameter D_{in} of the discharge vessel is in a range of $p_{igm} \times D_{in} \geq 5.2$ Pa.m.

This embodiment of the invention is based on the recognition that a higher filling pressure of the rare gas mixture leads to a reduced mercury depletion in the lamp. The filling pressure of the rare gas mixture in the conventional low-pressure mercury discharge lamp is usually made to depend on the lamp diameter, for which it is true that the greater the diameter of the lamp, the lower the filling pressure which is chosen. A rule of thumb usually applied is that the product of the pressure of the rare gas mixture and the diameter of the discharge vessel must not be greater than a certain value, for example 5.0 mPa. This leads to a maximum filling pressure of the rare gas mixture of 500 Pa for a discharge lamp having a diameter of 10 mm, to a maximum filling pressure of the rare gas mixture of 310 Pa for a discharge lamp with a diameter of 15.8 mm (5/8 inch), and to a maximum filling pressure of the rare gas mixture of 200 Pa for a diameter of 25.4 mm (8/8 inch). It is normally assumed that a higher filling pressure of the rare gas mixture has a significant negative effect on the luminous efficacy of the lamp. However, a higher filling pressure of the rare gas mixture has a positive influence on the mercury consumption of the discharge lamp, and thus on lamp life.

Not wishing to be held to any particular theory, it is believed that an explanation for the lower mercury consumption of the lamp at a higher filling pressure may be that the mercury ions, which move with high velocity through the discharge vessel, are decelerated by the additional rare gas atoms, so that said ions collide with the discharge vessel wall at a lower velocity and are less readily absorbed therein. As a result, there will be less wall blackening of the discharge lamp, and less mercury need be introduced into the lamp during manufacture for maintaining an unsaturated mercury vapor pressure throughout lamp life.

Preferably, $p_{igm} \times D_{in} \geq 8$ Pa.m. In particular, $p_{igm} \times D_{in} \geq 12.0$ Pa.m. It was found in experiments that the mercury consumption becomes lower in proportion as the filling pressure becomes higher. There is indeed a maximum filling pressure for which, when it is exceeded, the mercury consumption does not decrease substantially any more, while also the adverse effects on the luminous efficacy start to become noticeable. This maximum, however, seems to be dependent on the current through the lamp. The advantages of a higher filling pressure of the rare gas mixture manifest themselves especially in lamps of somewhat greater diameter, which had very low filling pressures of the rare gas mixture until now, such as a lamp having a diameter D_{in} of 15.9 mm (5/8 inch), or the widely used 25.4 mm (8/8 inch). Preferably, the filling pressure of the rare gas mixture P_{igm} of such a lamp is at least 200 Pa, more preferably at least 520 Pa, even more preferably at least 800 Pa.

An alternative, preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention is characterized in that at least a portion of an inner wall of the discharge vessel is provided with a protective layer, and in that the protective layer comprises a material selected from the group formed by oxides of scandium, yttrium and a further rare-earth metal, and/or a material selected from the group formed by borates of an alkaline-earth metal, scandium, yttrium and a further rare-earth metal, and/or a material selected from the group formed by phosphates of an alkaline-earth metal, scandium, yttrium and a further rare-earth metal.

Protective layers comprising the oxides, borates, and/or phosphates according to this embodiment of the invention appear to be very well resistant to the effect of the mercury-rare gas atmosphere which, in operation, prevails in the discharge vessel of a low-pressure mercury vapor discharge lamp. It has been found that the mercury consumption of low-pressure mercury vapor discharge lamps provided with a protective layer comprising said oxides, borates, and/or phosphates is considerably lower than with protective layers of the known low-pressure mercury vapor discharge lamp. The effect occurs both in straight parts and in bent parts of (tubular) discharge vessels of low-pressure mercury vapor discharge lamps. Bent lamp parts are used, for example, in hook-shaped low-pressure mercury vapor discharge lamps.

The protective layer in the low-pressure mercury vapor discharge lamp according to this embodiment of the invention further satisfies the requirements of light and radiation transmissivity. The protective layer can be easily provided as relatively thin, closed and homogeneous layer on the inner wall of a discharge vessel of a low-pressure mercury vapor discharge lamp. Said protective layer may be manufactured, for example, by flushing

the discharge vessel with a solution of a mixture of suitable metal-organic compounds (for example acetonates or acetates, for example, scandium acetate, yttrium acetate, lanthanum acetate, or gadolinium acetate mixed with calcium acetate, strontium acetate, or barium acetate) and boric acid or phosphoric acid diluted in water, whereupon the desired layer is obtained by drying and sintering.

Preferably, the alkaline-earth metal is calcium, strontium, and/or barium. A protective layer with said alkaline-earth metals exhibits a relatively high coefficient of transmission for visible light. Moreover, low-pressure mercury vapor discharge lamps with protective layers comprising calcium borate or phosphate, strontium borate or phosphate, or barium borate or phosphate have a good lumen maintenance. Preferably, the further rare-earth metal is lanthanum, cerium, and/or gadolinium. A protective layer with said rare-earth metals has a relatively high coefficient of transmission for ultraviolet radiation and visible light. Moreover, the layer can be provided in a relatively simple manner (for example with lanthanum acetate, cerium acetate, or gadolinium acetate mixed with boric acid or dilute phosphoric acid), which has a cost-saving effect, notably in a mass manufacturing process for low-pressure mercury vapor discharge lamps. Preferably, the protective layer comprises an oxide of yttrium and/or gadolinium. Such a protective layer has a relatively high coefficient of transmission for ultraviolet radiation and visible light. Moreover, the layers can be provided in a relatively easy manner (for example with yttrium acetate or gadolinium acetate), which has an additional cost-saving effect. Preferably, the protective layer has a thickness of approximately 5 nm to approximately 200 nm. At a layer thickness of more than 200 nm, there is a too great absorption of the radiation generated in the discharge space. At a layer thickness of less than 5 nm, there is interaction between the discharge and the wall of the discharge vessel. Layer thicknesses of at least substantially 90 nm are particularly suitable. The protective layer has a relatively high reflectivity in the wavelength range around 254 nm at such a layer thicknesses.

An alternative, preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention is characterized in that the discharge vessel is made from a glass comprising silicon dioxide and sodium oxide, with a glass composition comprising the following essential constituents, given in percentages by weight (wt.%): 60-80 wt.% SiO_2, and 10-20 wt.% Na_2O. A discharge vessel of a low-pressure mercury vapor discharge lamp having the above glass composition and comprising a protective layer is found to be very well resistant to the action of the mercury-rare gas atmosphere. In addition, the glass is comparatively inexpensive. In known discharge lamps use is made of a so-called

mixed alkali glass having a comparatively low SiO_2 content. The cost price of said glass is comparatively high. A comparison between the composition of the known glass and the glass in accordance with the invention shows that the alkali content is different. The glass in accordance with the invention is a so-called sodium-rich glass with a comparatively low potassium content, whereas the known glass is a so-called mixed alkali glass having approximately equal molar ratios of Na_2O and K_2O. An advantage is that the mobility of the alkali ions in the sodium-rich glass is comparatively high with respect to the mobility in the mixed alkali glass. In addition, melting of sodium-rich glass is comparatively easier than melting of mixed alkali glass.

Preferably, the glass composition includes the following constituents: 70-75 wt.% SiO_2, 15-18 wt.% Na_2O, and 0.25-2 wt.% K_2O. The composition of such a sodium-rich glass is similar to that of ordinary window glass and it is comparatively cheap with respect to the glass used in the known discharge lamp. In addition, the conductance of said sodium-rich glass is comparatively low; at 250°C the conductance is approximately $\log \rho = 6.3$, while the corresponding value of the mixed alkali glass is approximately $\log \rho = 8.9$.

The above described sodium-rich glass is suitably employed in combination with the protective layer as described. An alternative embodiment described below comprises a type of glass which exhibits a very low mercury consumption in the absence of a protective layer. To this end, an alternative preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention is characterized in that the discharge vessel is made from a glass that is substantially free of PbO and comprises, expressed as a percentage by weight (denoted by wt.%), the following constituents: 55–70 wt.% SiO_2, less than 0.1 wt.% Al_2O_3, 0.5–4 wt.% Li_2O, 0.5–3 wt.% Na_2O, 10–15 wt.% K_2O, 0–3 wt.% MgO, 0–4 wt.% CaO, 0.5–5 wt.% SrO, 7–10 wt.% BaO. This glass has a liquidus temperature (T_{liq}) which is at least 100°C less than the glasses which are usually employed. Such a glass has favorable fusion and processing properties. The glass composition is very suitable for drawing glass tubing and for use as a lamp envelope in a fluorescent lamp, in particular a tubular lamp envelope for a compact fluorescent lamp (CFL), in which the wall load is higher than in a "TL" lamp (normal straight tubular fluorescent lamp) owing to the smaller diameter of the lamp envelope. The glass is also suitable for manufacturing bulb-shaped lamp envelopes for fluorescent lamps, such as the so-called electrodeless or "QL" mercury vapor

discharge lamps. The glass is also suitable for manufacturing other parts of the lamp envelope, such as stems.

This glass composition does not comprise the detrimental components PbO, F, As_2O_3, and Sb_2O_3. The SiO_2 content of the glass in accordance with the invention is limited to 55-70 wt.%. In combination with the other constituents, said SiO_2 content leads to a readily fusible glass. As is known in the art, SiO_2 serves as a network former. If the SiO_2 content is below 55 wt.%, the cohesion of the glass and the chemical resistance are reduced. An SiO_2 content above 70 wt.% hampers the vitrification process, causes the viscosity to become too high, and increases the risk of surface crystallization. The mere absence of Al_2O_3 has the following advantages. The liquidus temperature (T_{liq}) is reduced by avoiding the forming of feldspar-like crystals, for example microcline or orthoclase ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$). The absence of Al_2O_3 in the glass composition, compared with the glass compositions known in the art, does not have a detrimental influence on the chemical resistance nor on the resistance against weathering of the glass. In addition, the glass without Al_2O_3 exhibits a low crystallization tendency as well as a viscosity and softening temperature (T_{soft}) enabling a good processing of the glass.

The alkali metal oxides Li_2O, Na_2O, and K_2O are used as melting agents and lead to a reduction of the tile viscosity of the glass. If both alkali metal oxides are used in the above composition, then the so-called mixed-alkali effect causes the electrical resistance to be increased and T_{liq} to be reduced. In addition, it is predominantly the alkali metal oxides that determine the thermal expansion coefficient α of the glass. This is important because it must be possible to seal the glass to the stem glass and/or the current supply conductors, for example, of copper-plated iron/nickel wire in such a way that the glass is free from stress. If the alkali-metal-oxide content is below the indicated limits, the glass will have a too low α-value (coefficient of thermal expansion) and T_{soft} (softening point) will be too high. Above the indicated limits, the α-value will be too high. Li_2O causes a greater reduction of T_{soft} than K_2O, which is desirable to obtain a wide so-called "Working Range" (= T_{work}–T_{soft}). Too high an Li_2O content leads to an excessive increase of T_{liq}. In addition, Li_2O is an expensive component, so that, also from an economical point of view, the Li_2O content is limited.

BaO has the favorable property that it causes the electrical resistance of the glass to increase and T_{soft} to decrease. Below 7 wt.%, the melting temperature (T_{melt}), T_{soft} and the working temperature (T_{work}) increase too much. Above 10 wt.%, the liquidus temperature (T_{liq}) and hence the crystallization tendency increase too much. The alkaline

earth metal oxides SrO, MgO and CaO have the favorable property that they lead to a reduction of T_{melt}.

Preferably, the composition of the glass comprises: 65–70 wt.% SiO_2, 1.4–2.2 wt.% Li_2O, 1.5–2.5 wt.% Na_2O, 11–12.3 wt.% K_2O, 1.8–2.6 wt.% MgO, 2.5–5 wt.% CaO, 2–3.5 wt.% SrO, 8–9.5 wt.% BaO. The glass according to this preferred embodiment of the invention has a favorable T_{liq} ≤800°C and hence hardly tends towards crystallization during the manufacture of the glass and during drawing of glass tubing from said glass. By virtue of a wide Working Range of at least 310°C and a low T_{soft} (700°C), the glass can be shaped into a tube without any problems by means of, for example, the Danner or the Vello process, known in the art. Said glass has favorable fusion and processing properties. The thermal expansion coefficient can be tuned to match the glass with other glasses. The glass composition according to the preferred embodiment of the invention is very suitable for drawing glass tubing and for use as a lamp envelope or stem in a fluorescent lamp.

Preferably, the sum of the concentrations of Li_2O, Na_2O and K_2O is in a range from 14 to 16 wt.%. Preferably, the sum of the concentrations of SrO and BaO is in a range from 10 to 12.5 wt.%. Keeping the concentrations in the preferred ranges reduces the cost price of the glass. The glass composition in accordance with the invention can be refined by means of Na_2SO_4, so that the glass may contain up to 0.2 wt.% SO_3. The glass may additionally contain an impurity in the form of at most 0.2 wt.% Fe_2O_3, which originates from the raw materials used. If necessary, up to 0.2 wt.% CeO_2 is added to the glass to absorb undesirable UV radiation.

In order to attain a satisfactory lumen maintenance of the lamp and a suppressed mercury consumption, it is known in the art to provide the inner surface of the lamp envelope with a protective coating, for example of Y_2O_3. In the case of a glass composition according to the above described preferred embodiment of the low-pressure mercury vapor discharge lamp according to the invention, a protective coating and hence an additional process step are no longer necessary, leading to a cost reduction in lamp manufacture.

In mercury vapor discharge lamps, a luminescent layer converting UV to other wavelengths (for example, to UV-A, UV-B and/or and UV-C) is normally present on an inner wall of the discharge vessel. However, the luminescent layer also contributes to mercury consumption in the discharge lamp. Physical contact between the discharge in the discharge vessel and the luminescent layer can be avoided by applying the fluorescent layer to the outside surface of the discharge vessel. To this end, a preferred embodiment of the low-

pressure mercury vapor discharge lamp according to the invention is characterized in that the discharge vessel is provided with a luminescent layer comprising a luminescent material at a side facing away from the discharge space. In order to make the luminescent layer scratch-resistant, the luminescent layer is preferably embedded in an inorganic matrix material. A suitable inorganic matrix material is aluminum phosphate.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig. 1A is a cross-sectional view of an embodiment of the low-pressure mercury-vapor discharge lamp in accordance with the invention in longitudinal section;

Fig. 1B shows a detail of Fig. 1A, which is partly drawn in perspective;

Fig. 2 is a cross-sectional view of an embodiment of a compact fluorescent lamp comprising a low-pressure mercury vapor discharge lamp according to the invention;

Fig. 3 shows an alternative embodiment of the low-pressure mercury vapor discharge lamp according to the invention;

Fig. 4 shows the relative luminous flux of low-pressure mercury vapor discharge lamps as function of the relative ambient temperature;

Fig. 5 shows the relative luminous flux of a low-pressure mercury vapor discharge lamp according to the invention, and

Fig. 6 shows the amount of mercury as a function of the product of the internal diameter D_{in} and the length of the discharge vessel L_{dv}.

The Figures are purely diagrammatic and not drawn to scale. Notably, some dimensions are shown in a strongly exaggerated form for the sake of clarity. Similar components in the Figures are denoted as much as possible by the same reference numerals.

Fig. 1A shows a low-pressure mercury-vapor discharge lamp comprising a glass discharge vessel having a tubular portion 11 surrounding a longitudinal axis 2, which discharge vessel transmits radiation generated in the discharge vessel 10 and is provided with a first and a second end portion 12a; 12b, respectively. In this example, the tubular portion 11 has a length L_{dv} of 120 cm and an inside diameter D_{in} of 24 mm. The discharge vessel 10 encloses, in a gastight manner, a discharge space 13 containing a filling of mercury and an

inert gas mixture comprising, for example, argon. The side of the tubular portion 11 facing the discharge space 13 is provided with a protective layer 17 according to an embodiment of the invention. In an alternative embodiment, the first and second end portions 12a; 12b are also coated with a protective layer. In fluorescent discharge lamps, the side of the tubular portion 11 facing the discharge space 13 is in addition coated with a luminescent layer 16 which comprises a luminescent material (for example a fluorescent powder) which converts the ultraviolet (UV) light generated by fallback of the excited mercury into (generally) visible light. In an alternative embodiment, the luminescent layer 16 is in addition provided with a further protective layer (not shown in Fig. 1A).

A luminescent layer present on the inside of the discharge vessel contributes to the consumption of mercury in the discharge lamp. To avoid physical contact between the discharge in the discharge vessel and the luminescent layer, the fluorescent layer is provided on the outside of the discharge vessel in an alternative embodiment of the low-pressure mercury vapor discharge lamp according to the invention. In order to make the luminescent layer scratch-resistant, the luminescent layer is preferably embedded in an inorganic matrix material. A suitable inorganic matrix material is aluminum phosphate. By way of example, an 8 W so-called TUV lamp (length approximately 30 cm) without lamp caps was dipped into a phosphor suspension after cleaning. An aqueous suspension with the well-known luminescent materials YOX and LAP was used. After the lamp had been removed from the suspension, the phosphor layer (density 3-4 mg/cm^2) was dried in hot air (approximately 80°C) in a standard manner. After drying, the lamp was heated for approximately 15 minutes at approximately 450°C to remove the binder. Thereafter, the discharge lamp was dipped into a sol-gel solution of aluminum dehydrogenated phosphate. Preferably, nano-sized Al_2O_3 particles are dispersed in the sol-gel solution. After drying and baking, in a similar manner as described above, the luminescent layer was embedded in an inorganic matrix of aluminum phosphate, which is very well scratch-resistant. The embedded phosphor layer may alternatively be applied by spray-coating or other coating methods instead of by dipping. For elongate fluorescent lamps, spraying is preferred to dipping. Inorganic sol-gel matrix materials other than aluminum dehydrogenated phosphate are suitable, provided that such materials are transparent to and resistant against UV light.

In the example of Fig. 1A, means for maintaining a discharge in the discharge space 13 are electrodes 20a; 20b arranged in the discharge space 13, said electrodes 20a; 20b being supported by the end portions 12a; 12b. The electrode 20a; 20b is a winding of tungsten covered with an electron-emitting substance, in this case a mixture of barium oxide,

calcium oxide, and strontium oxide. Current-supply conductors 30a, 30a'; 30b, 30b' of the electrodes 20a; 20b, respectively, pass through the end portions 12a; 12b and issue from the discharge vessel 10 to the exterior. The current-supply conductors 30a, 30a'; 30b, 30b' are connected to contact pins 31a, 31a'; 31b, 31b' which are secured to a lamp cap 32a, 32b. In general, an electrode ring (not shown in Figure 1A), on which a glass capsule for dispensing mercury is clamped, is arranged around each electrode 20a; 20b.

In the example shown in Fig. 1A, the electrode 20a; 20b is surrounded by an electrode shield 22a; 22b which, in accordance with an embodiment of the invention, is made from a ceramic material. Preferably, the electrode shield is made from a ceramic material comprising aluminum oxide. Particularly suitable electrode shields are manufactured from so-called densely sintered Al_2O_3, also referred to as DGA. Preferably, the temperature of the electrode shield 22a; 22b is 450°C during nominal operation. At said temperatures, dissociation causes mercury bonded to BaO or SrO on the electrode shield 22a; 22b to be released again, so that it is available for the discharge in the discharge space. In an alternative embodiment, the electrode shield 22a; 22b is made from stainless steel. At said high temperatures, such an electrode shield is dimensionally stable, corrosion-resistant, and exhibits a relatively low heat emissivity. A material which can suitably be used to manufacture the electrode shield is chromium-nickel-steel (AISi 316) having the following composition (in % by weight): at most 0.08% C, at most 2% Mn, at most 0.0045% P, at most 0.030% S, at most 1% Si, 16-18% Cr, 10-14% Ni, 2-3% Mo and the rest Fe. It has been observed that the outside surface of such an electrode shield becomes slightly darker in color during the manufacture of the discharge lamp. Another material which is particularly suitable for the manufacture of the electrode shield is Duratherm 600, which is a CoNiCrMo alloy having an increased corrosion resistance, the composition of which is as follows: 41.5% Co, 12% Cr, 4% Mo, 8.7% Fe, 3.9% W, 2% Ti, 0.7% Al and the rest Ni.

Fig. 1B is a partly perspective view of a detail shown in Fig. 1A, the end portion 12a supporting the electrode 20a via the current supply conductors 30a, 30a'. The electrode 22a shield is supported by a support wire 26a, 27a, which is provided in the end portion 12a in this example. In an alternative embodiment, the support wire 26a, 27a is connected to one of the current supply conductors 30a, 30a'. In the example shown in Fig. 2, the support wire 26a, 27a is composed of a section 26a of iron, having a thickness of approximately 0.9 mm, and a section 27a manufactured from stainless steel. The section 27a of the support wire 26a, 27a is connected by means of welded joints to, on the one hand, the electrode shield 22a and, on the other hand, to the further section 26a of the support wire 26a,

27a. Stainless steel has a very low coefficient of thermal conduction with respect to the known materials (for example iron) used for support wires. The electrode shield 22a is capable of maintaining its comparatively high temperature because the section 27a of the support wire 26a, 27a effectively reduces the dissipation of heat from the electrode shield 22a. A stainless steel section 27a of the support wire having a thickness of 0.4 mm is particularly suitable. In a further alternative embodiment, the electrode shield is directly provided on the current supply conductors, for example in that the electrode shield is provided with contracted portions which are a press fit on the current supply conductors.

Fig. 2 shows a compact fluorescent lamp comprising a low-pressure mercury vapor discharge lamp. Similar components in Fig. 2 are denoted as much as possible by the same reference numerals as in Figs. 1A and 1B. The low-pressure mercury-vapor discharge lamp is in this case provided with a radiation-transmitting discharge vessel 10 having a tubular portion 11 enclosing, in a gastight manner, a discharge space 13 having a volume of approximately 25 cm^3. The discharge vessel 10 is a glass tube which is at least substantially circular in cross-section and has an (effective) internal diameter D_{in} of approximately 10 mm. In this example, the tubular portion 11 has a total length L_{dv} (not shown in Fig. 2) of 40 cm. The tube is bent in the form of a so-called hook and, in this embodiment, it has a number of straight parts, two of which, referenced 31, 33, are shown in Fig. 2. The discharge vessel further comprises a number of arc-shaped parts, two of which, referenced 32, 34, are shown in Fig. 2. The side of the tubular portion 11 facing the discharge space 13 is provided with a protective layer 17 according an embodiment of the invention and with a luminescent layer 16. In an alternative embodiment, the luminescent layer has been omitted. In a further alternative embodiment, the luminescent layer is coated with a further protective layer (not shown in Fig. 2). The discharge vessel 10 is supported by a housing 70 which also supports a lamp cap 71 provided with electrical and mechanical contacts 73a, 73b, which are known per se. In addition, the discharge vessel 10 is surrounded by a light-transmitting envelope 60 which is attached to the lamp housing 70. The light-transmitting envelope 60 generally has a matt appearance.

Preferably, the glass of the discharge vessel of the low-pressure mercury-vapor discharge lamp has a composition comprising silicon dioxide and sodium oxide as important constituents. In the example shown in Fig. 2, the discharge vessel in accordance with the invention is made from so-called sodium-rich glass. Particularly preferred is a glass of the following composition: 70-74 wt.% SiO_2, 16-18 wt.% Na_2O, 0.5-1.3 wt.% K_2O, 4-6 wt.%

CaO, 2.5-3.5 wt.% MgO, 1-2 wt.% Al_2O_3, 0-0.6 wt.% Sb_2O_3, 0-0.15 wt.% Fe_2O_3, and 0-0.05 wt.% MnO.

In an embodiment of the low-pressure mercury vapor discharge lamp, various concentrations of an $Me(Ac)_2$ solution, in which Me = Sr or Ba, and H_3BO_3 were added to solutions comprising various concentrations of $Y(Ac)_3$ (yttrium acetate) for manufacturing the protective layer 17. The molar ratio between $Me(Ac)_2$ and H_3BO_3 was kept constant. For the purpose of comparison, a 1.25% by weight of $Y(Ac)_3$ was also prepared. After rinsing and drying, the tubular discharge vessels were provided with a coating by passing an excess of the afore-mentioned solutions through the vessels. After coating, the discharge vessels were dried in air at a temperature of approximately 70°C. Subsequently, the discharge vessels were provided with a luminescent coating comprising three known phosphors, namely a green-luminescing material with terbium-activated cerium magnesium borate (CBT in CFL en CAT in TL), a blue-luminescing material with bivalent europium-activated barium magnesium aluminate, and a red-luminescing material with trivalent europium-activated yttrium oxide. After coating, the discharge vessels were bent in the known hook shape with straight parts 31, 33 and arcuate parts 34 (see Fig. 2). A number of discharge vessels was subsequently assembled into low-pressure mercury vapor discharge lamps in the customary manner. In an alternative embodiment, the discharge vessel is first bent and coated afterwards.

Table I shows, by way of example, the result of the mercury consumption (expressed in μg Hg) of various low-pressure mercury vapor discharge lamps (Ecotone Ambiance 20 W). The example of Table I relates to a low-pressure mercury vapor discharge lamp as shown in Fig. 2 with a protective layer comprising Sr, in which the tubular discharge vessel is bent in the form of a hook and has four straight parts 31, 33 and three arcuate parts 34. The mercury contents (in μg Hg) of the protective layers were (destructively) measured for six lamps after several thousands of operating hours. The values found for the mercury consumption were averaged.

Table I

Mercury consumption (in μg Hg) of various parts of discharge lamps (Ecotone Ambiance 20 W) with and without a protective layer.

	Protective layer	Hg consumption	
		straight parts	bent parts
1	No	50	100
2	Y_2O_3	10	40
3	Y_2O_3 + Sr borate	5	10

Table I shows that the mercury consumption is considerably lower than in discharge lamps without a protective layer or with a known Y_2O_3 layer, both in the straight parts 31, 33 and in the bent parts 34 of the discharge vessel. In the example of Table I the protective layer comprises yttrium oxide and strontium borate. Roughly speaking, the mercury consumption is improved, i.e. less mercury consumption, by a factor of two from a discharge lamp without a protective layer to a discharge lamp provided with the known Y_2O_3 protective layer, and the mercury consumption further improves by another factor of two from a discharge lamp provided with the known Y_2O_3 protective layer to a discharge lamp provided with a protective according to an embodiment of the invention. In the bent or arc-shaped parts the gain is substantially larger (a factor of four). Due to the protective coating, the mercury consumption in, notably, the bent parts 34 of the discharge vessel is improved considerably. The latter is notably the case with relatively thick protective layers because the discharge vessel is stretched by approximately 30% during bending, so that the protective layer is thinner at the bent parts 34 than at the straight parts 31, 33 of the discharge vessel 10. It is to be noted that the color point of the low-pressure mercury vapor discharge lamp provided with the protective layers satisfies the customary requirements ($x \approx 0.31$, $y \approx 0.32$).

A particularly suitable glass composition from which the discharge vessel can be made which can be used without protective coating comprises 68 wt.% SiO_2, less than 0.1 wt.% Al_2O_3, 1.6 wt.% Li_2O, 1.9 wt.% Na_2O, 11 wt.% K_2O, 2.4 wt.% MgO, 4.5 wt.% CaO, 2.1 wt.% SrO, 8.3 wt.% BaO. The glass composition also comprises approximately 0.05 wt.% Fe_2O_3, approximately 0.06 wt.% SO_3, and approximately 0.05 wt.% CeO_2. The sum of the concentrations of Li_2O, Na_2O and K_2O in this embodiment of the glass composition is approximately 14.5 wt.%, and the sum of the concentrations of SrO and BaO is approximately 10.4 wt.%, giving the glass a relatively low cost price. The melting operation

is carried out in a platinum crucible in a gas-fired furnace at 1450°C. The starting materials used are quartz sand, dolomite ($CaCO_3 \cdot MgCO_3$) and the carbonates of Li, Na, K, Sr and Ba. The refining agent is Na_2SO_4. During melting and further processing no particular problems occur. The average coefficient of thermal expansion between 25°C and 300°C: $\alpha_{25\text{-}300} = 9.2$. In addition, $T_{liq} = 775°C$, $T_{soft} = 700°C$, $T_{work} = 1015°C$, and the Working Range $= T_{work} - T_{soft} = 315°C$.

Fig. 3 shows an alternative embodiment of the low-pressure mercury vapor discharge lamp according to the invention. The discharge vessel 210 of the so-called electrodeless low-pressure mercury vapor discharge lamp has a pear-shaped enveloping portion 216 and a tubular invaginated portion 219 which is connected to the enveloping portion 216 via a flared portion 218. The invaginated portion 219 accommodates a coil 233 outside a discharge space 211 surrounded by the discharge vessel 210, which coil has a winding 234 of an electrical conductor, thus constituting means for maintaining an electric discharge in the discharge space 211. The coil 233 is fed via current supply conductors 252, 252' with a high-frequency voltage during operation, i.e. a frequency of more than approximately 20 kHz, for example approximately 3 MHz. The coil 233 surrounds a core 235 of a soft-magnetic material (shown in broken lines). Alternatively, a core may be absent. In an alternative embodiment, the coil is arranged, for example, in the discharge space 211. The internal diameter D_{in} and the length of the discharge vessel L_{dv} are also indicated in Fig. 3. Normally the internal diameter D_{in} ranges from approximately 80 mm to approximately 140 mm. In the example of Fig. 3 the internal diameter D_{in} and the length of the discharge vessel L_{dv} are approximately equal.

Fig. 4 shows the relative luminous flux of low-pressure mercury vapor discharge lamps as a function of the relative ambient temperature for various values of the constant C. The light output or luminous flux φ is expressed as a percentage of the maximum luminous flux φ_{max}, and the ambient temperature T_{amb} is given relative to the temperature at the maximum luminous flux T_{max}. Curve (a) in Fig. 4 depicts the situation for a known low-pressure mercury vapor discharge lamp with a relatively high amount of mercury dosed into the discharge vessel during manufacture of the discharge lamp. It can be observed from curve (a) that the luminous flux φ is dependent on the ambient temperature T_{amb}, i.e. the higher the ambient temperature, the lower the light output of the discharge lamp. Such a temperature-dependent behavior restricts the possibilities for further miniaturization of low-pressure mercury vapor discharge lamps considerably, in particular of compact fluorescent

lamps in which the discharge vessel 10 is surrounded by a light-transmitting envelope 60 (see Fig. 2).

Curve (b) in Fig. 4 depicts the situation for an unsaturated low-pressure mercury vapor discharge lamp according to the invention. In this example C≈0.0013. In the situation of curve (b) in Fig. 4, the discharge lamp is supplied with an amount of mercury which causes the discharge lamp to operate under unsaturated mercury conditions when the ambient temperature is approximately equal to the maximum temperature T_{max}. It can be seen that the luminous flux is independent of the temperature for ambient temperatures higher than T_{max}. The trend in the marketplace towards further miniaturization and towards more light output can be followed with a mercury vapor discharge lamp operating under unsaturated mercury conditions.

Curve (c) in Fig. 4 depicts the situation for an unsaturated low-pressure mercury vapor discharge lamp according to the invention. In this example C≈0.0021. In the situation of curve (c) in Fig. 4, the discharge lamp is supplied with such an amount of mercury as results in 5% less light than under optimal conditions when the lamp becomes unsaturated (corresponding to approximately 21/13 times the optimal Hg dose). It can be seen that the luminous flux is independent of the temperature for ambient temperatures approximately 10°C above the maximum temperature.

Curve (d) in Fig. 4 depicts the situation for an unsaturated low-pressure mercury vapor discharge lamp according to the invention. In this example C≈0.0040. In the situation of curve (d) in Fig. 4, the discharge lamp is supplied with such an amount of mercury as results in 10% less light than under optimal conditions when the lamp becomes unsaturated (corresponding to approximately 40/13 times the optimal Hg dose). It can be seen that the luminous flux is independent of the temperature for ambient temperatures approximately 15°C above the maximum temperature.

Curve (e) in Fig. 4 depicts the situation for an unsaturated low-pressure mercury vapor discharge lamp according to the invention. In this example C≈0.008. In the situation of curve (e) in Fig. 4, the discharge lamp is supplied with such an amount of mercury as results in 20% less light than under optimal conditions when the lamp becomes unsaturated (corresponding to approximately 80/13 times the optimal Hg dose). It can be seen that the luminous flux is independent of the temperature for ambient temperatures approximately 25°C above the maximum temperature.

Unsaturated mercury vapor discharge lamps are quick starters and have a short run-up time. By way of example, the initial radiation output of a typical unsaturated mercury vapor discharge lamp is approximately 38%, whereas the initial radiation output for a known discharge lamp provided with an amalgam is approximately 6%. The "run-up time" of the same unsaturated discharge lamp is approximately 75 seconds, whereas the run-up time for a known discharge lamp provided with an amalgam is approximately 210 seconds. In addition, unsaturated mercury vapor discharge lamps have a 25% lower ignition voltage than a known discharge lamp provided with an amalgam. Unsaturated mercury vapor discharge lamp typically contain less than 0.1 mg mercury.

It was observed from experiments that the lumen maintenance of unsaturated mercury vapor discharge lamp is higher than approximately 98% at 10,000 hours. Fig. 5 shows a typical example of the relative light output of a low-pressure mercury vapor discharge lamp according to the invention (corresponding to a discharge lamp under the conditions of curve (d) ($C \approx 0.04$) in Fig. 4). The light output or luminous flux φ is expressed as a percentage of the maximum luminous flux φ_{max}, and the time t is given in hours. Note that the behavior of an unsaturated mercury vapor discharge lamp is somewhat different from what is normally observed for discharge lamps containing known amounts of mercury. The maximum light output is not reached until after more than 5000 hours.

Fig. 6 shows the amount of mercury as a function of the product of the internal diameter D_{in} and the length of the discharge vessel L_{dv} for three different values of C, i.e. C=0.0013, C=0.0021 and C=0.004. The amounts of mercury dosed during manufacturing of the discharge lamp are considerably higher in known low-pressure mercury vapor discharge lamps. For normal tubular fluorescent lamps, with $D_{in} \times L_{dv}$ in the range from 12.10^3 t to 35.10^3 mm^2, the amount of mercury is in the range of 3.10^3–15.10^3 µg Hg. For known compact fluorescent lamps with $D_{in} \times L_{dv}$ in the range from approximately 10^3–10.10^3 mm^2, the amount of mercury is in the range of 3.10^3–10.10^3 µg Hg.

According to the measures of the invention, unsaturated lamps combine a minimum mercury content with an improved lumen per Watt performance at elevated temperatures.

It will be evident that many variations within the scope of the invention can be conceived by those skilled in the art.

The scope of the invention is not limited to the embodiments. The invention resides in each new characteristic feature and each combination of novel characteristic

features. Any reference signs do not limit the scope of the claims. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim. Use of the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.